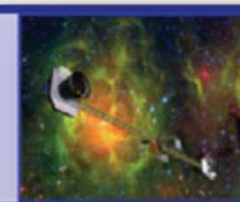
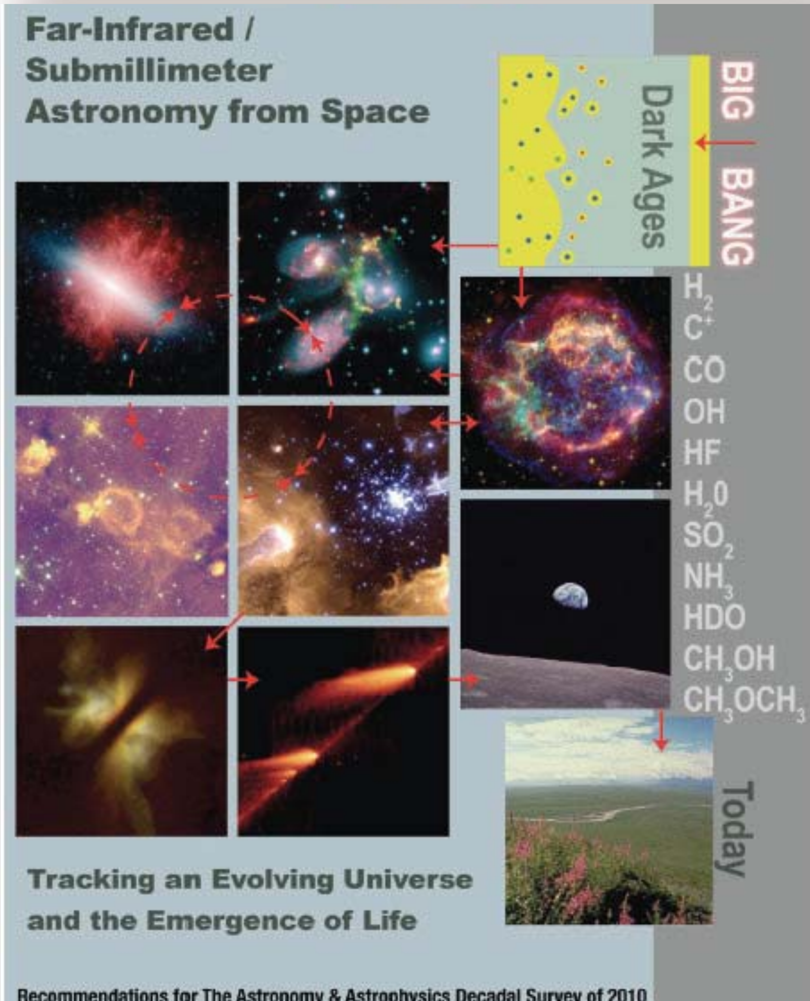
Motivation and prospects for spatio-spectral interferometry in the far-infrared

Dave Leisawitz
Goddard Space Flight Center

The Far-IR community plan



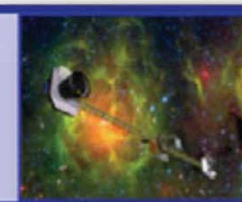


Consensus developed through a series of workshops, starting in 1998

Compelling science case for high angular resolution imaging and spectroscopy, and mission concepts

A robust plan – it has evolved over the years, but has consistently called for high resolution

A vision without borders

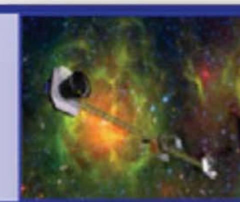


The international far-infrared astrophysics community shares this vision

Projects underway in Europe and Japan

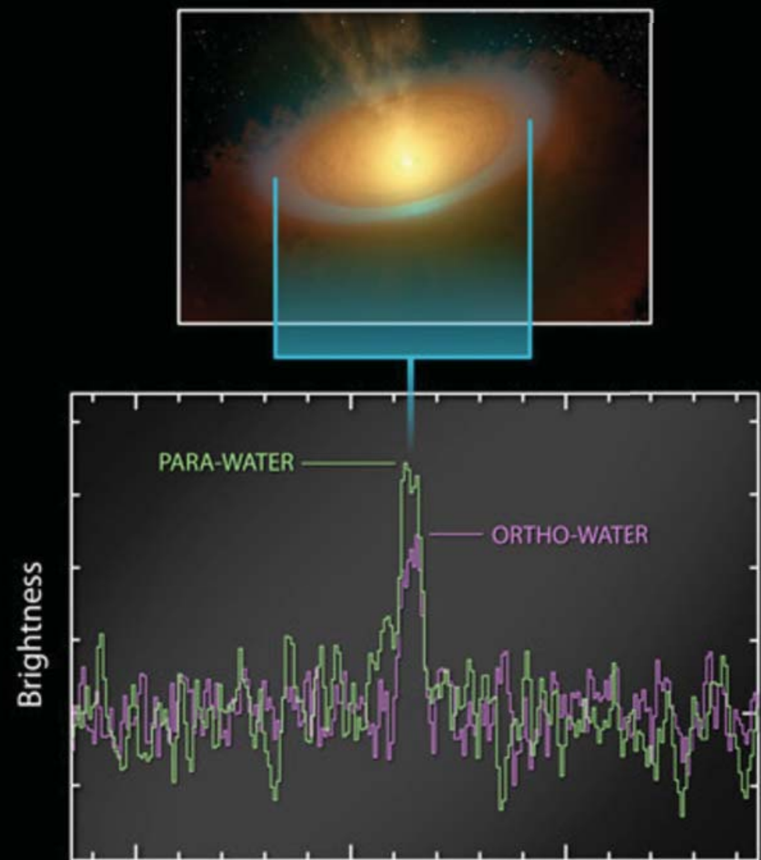
Large space missions are collaborative

Outline



- Scientific motivation for high resolution (and spectroscopy) in the far-infrared spectral range, ~25 to 400 micro-meters
- How can we turn the community's vision into reality?
- What are the technical challenges and practical considerations?

Forming habitable planets



HIFI Spectroscopic Signatures of Water Vapor in TW Hydrae Disk
ESA/NASA/JPL-Caltech/M. Hogerheijde (Leiden Observatory)

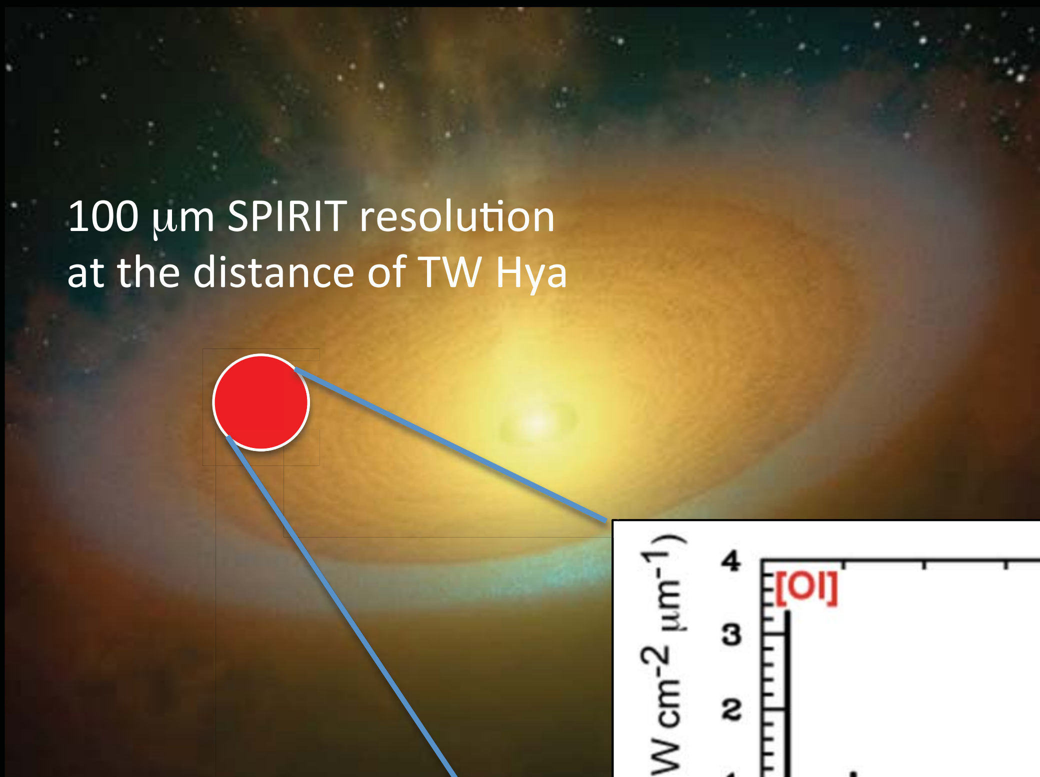
How did the Earth acquire its water? How do habitable plants form?

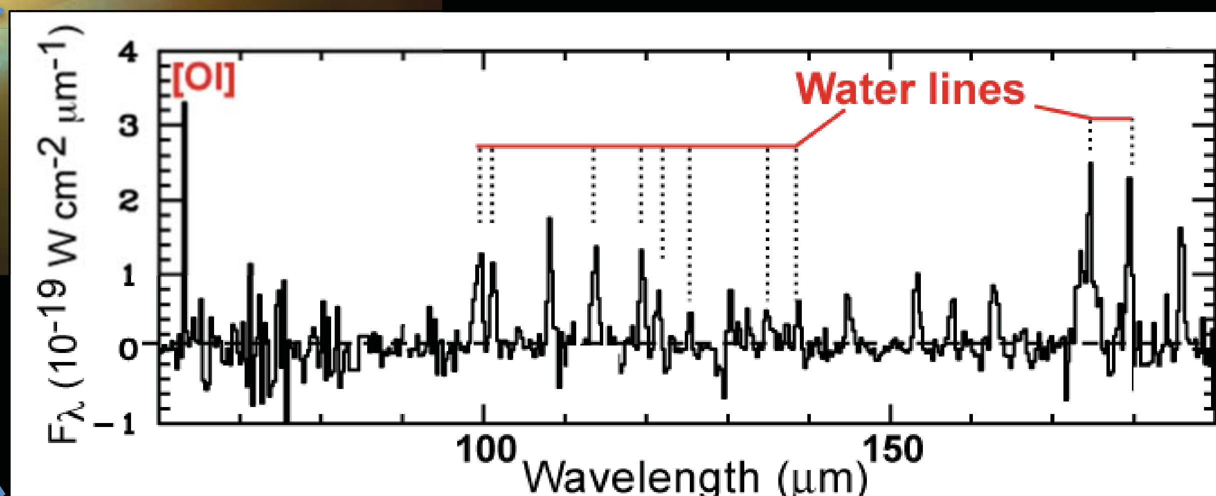
Herschel observes developing planetary systems and measures water, but it can't resolve these objects spatially.

Theorists have models, but lack unique solutions.

Spatially resolved spectroscopy will break model degeneracy.

Forming habitable planets

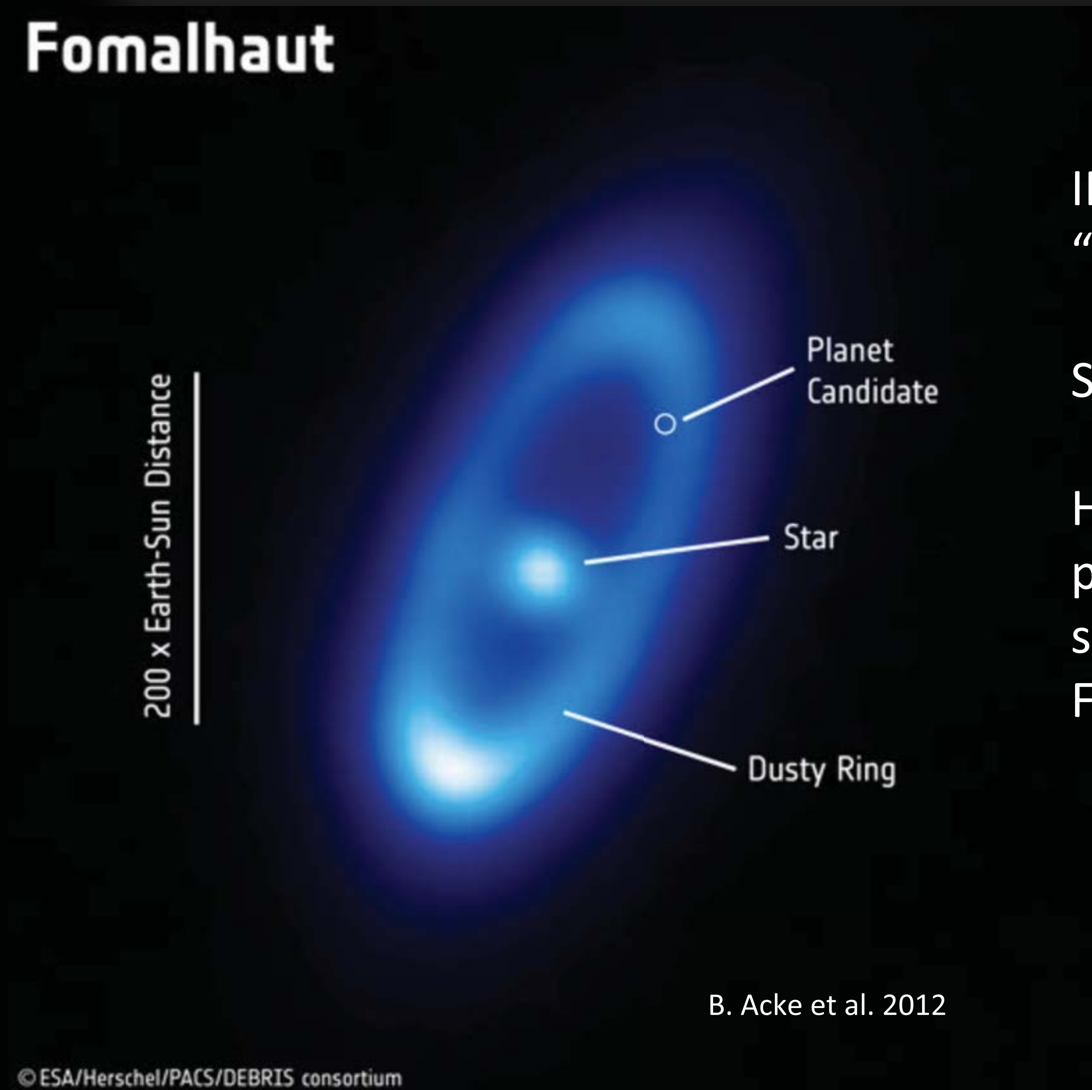




How did the Earth acquire its water? How do habitable plants form?

SPIRIT will provide the missing information!

Debris disks: from the Fab 4 …



IRAS discovered the "fabulous 4" debris disks

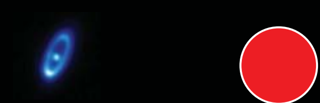
Spitzer imaged them

Herschel vastly improved the picture and captured this stunning image of the Fomalhaut disk

… to hundreds

At 100 pc

To image hundreds of debris disks and tap them for information about planetary systems, we'll have to image disks out to 100 pc.

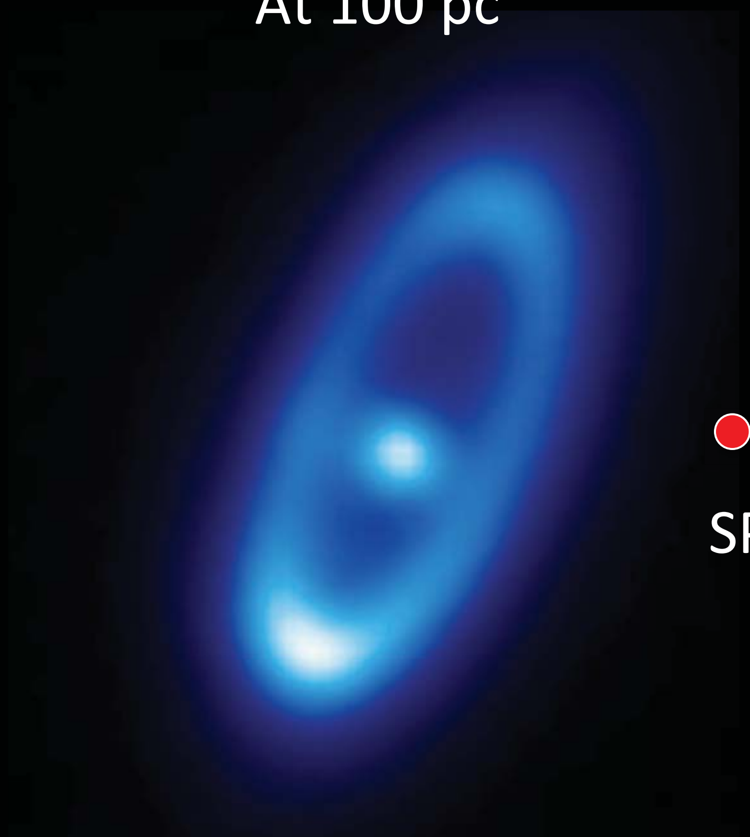


Herschel at 70 μm

A 3.5 m telescope isn't big enough.

… to study planetary systems

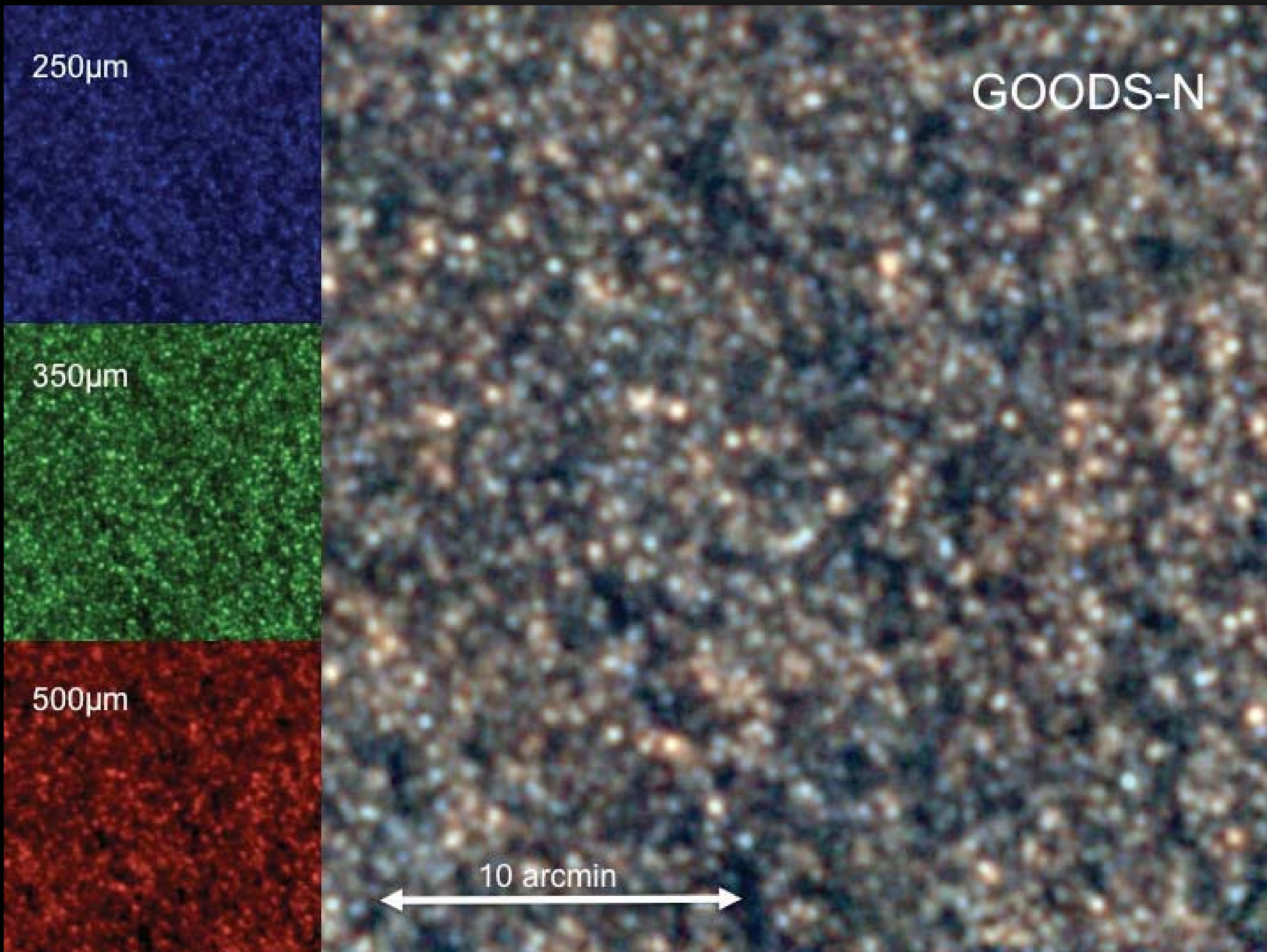
At 100 pc



SPIRIT at 70 μm

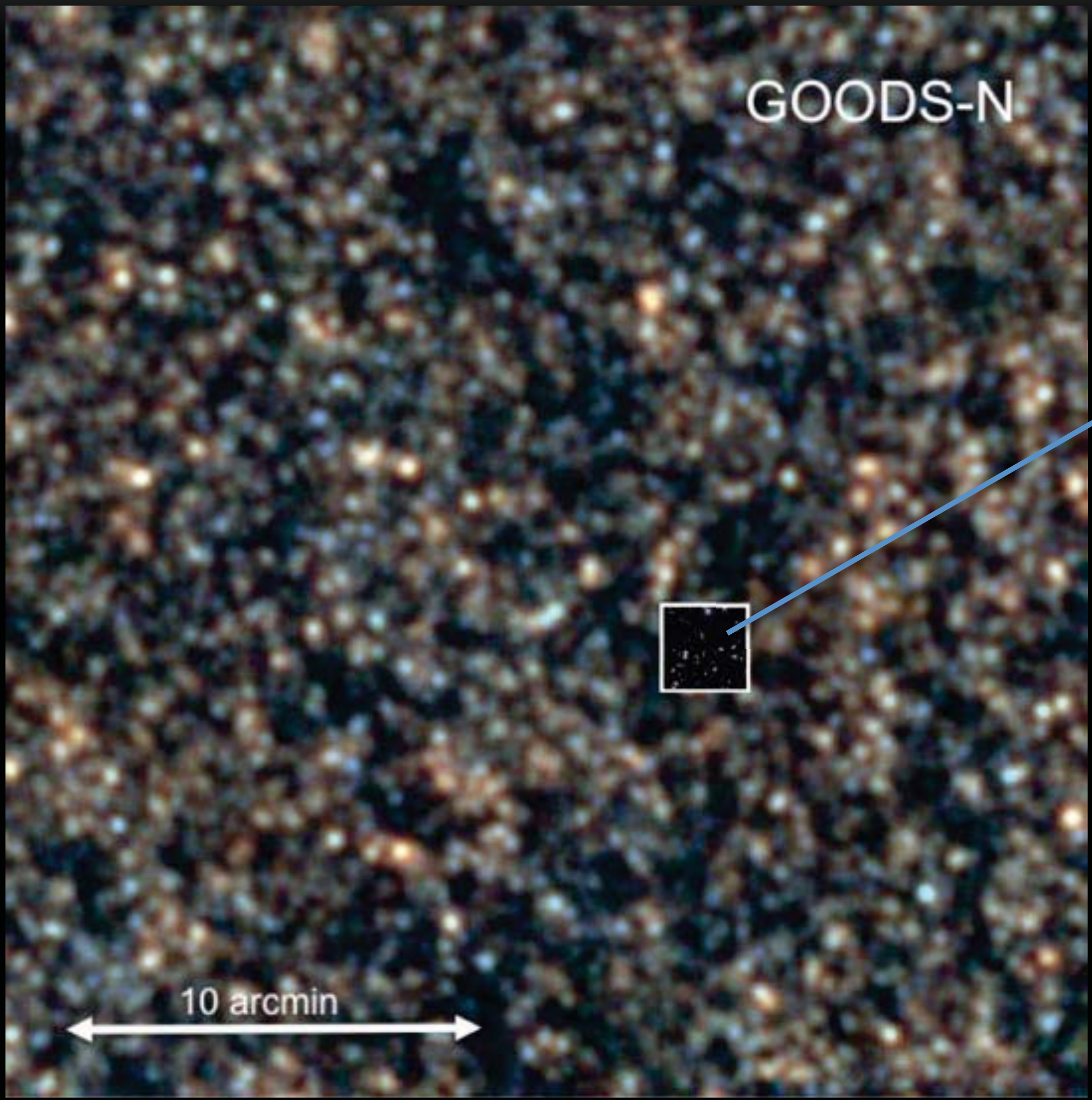
But SPIRIT will image <u>hundreds</u> of debris disks!

Probing the universe deeply

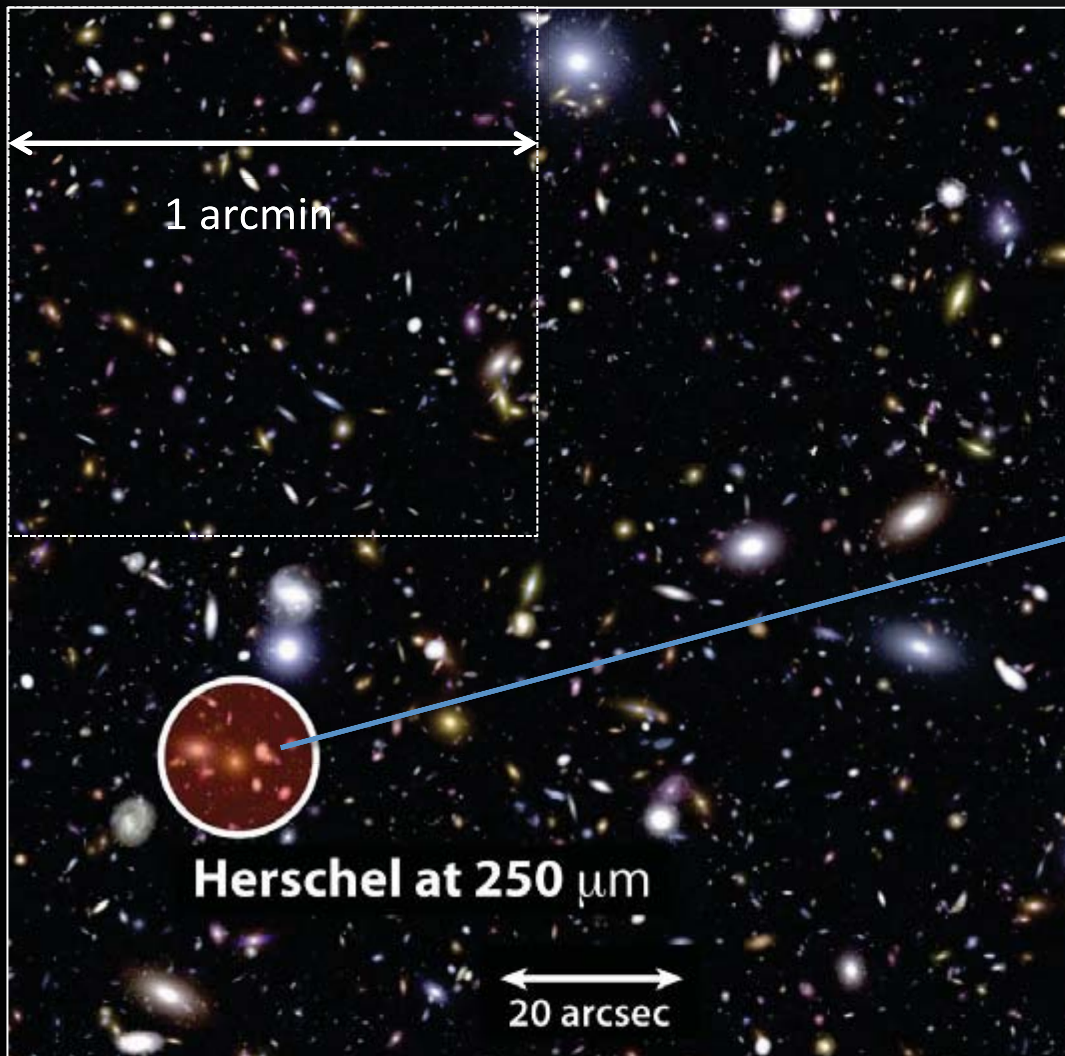


Herschel deep field

Probing the universe deeply



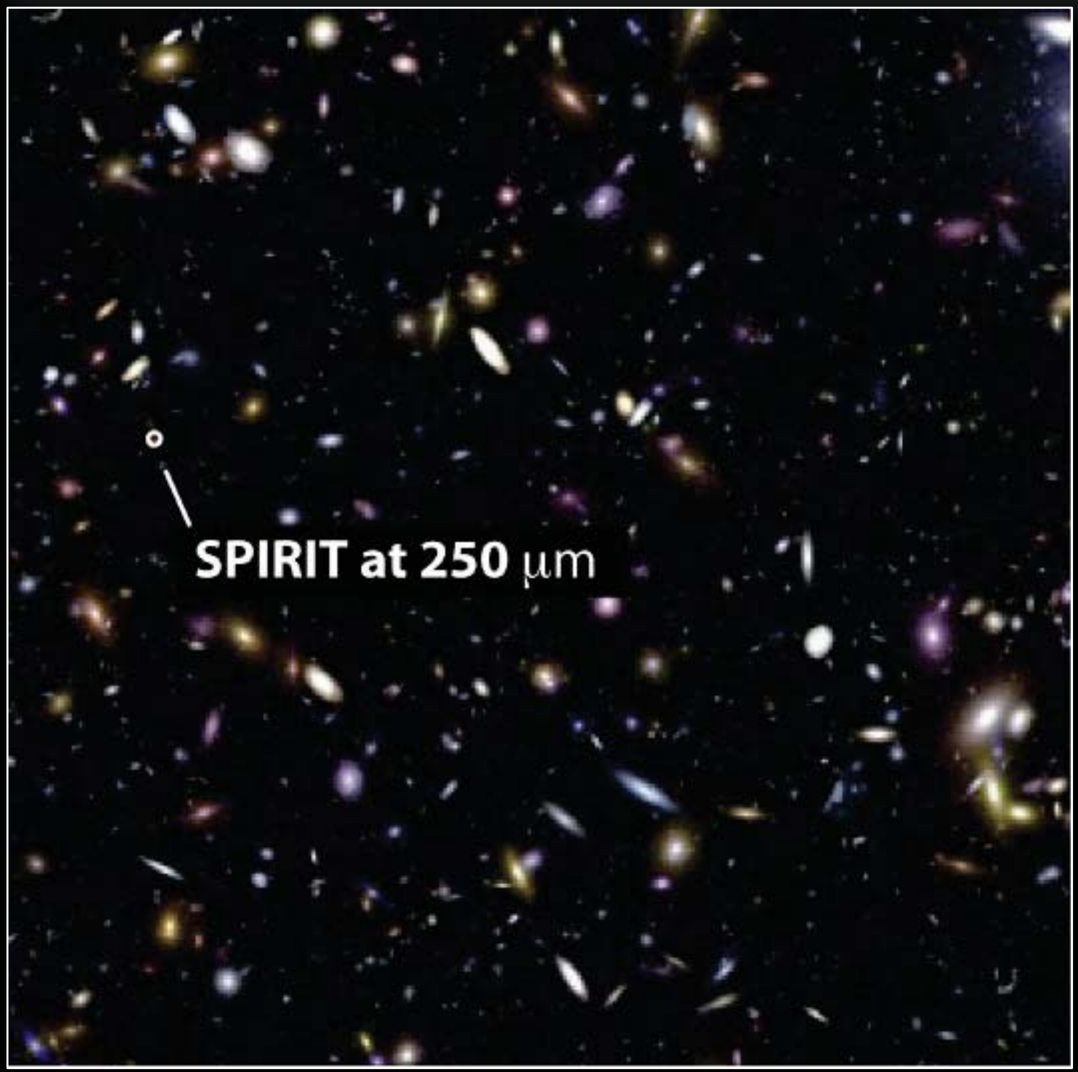
Probing the universe deeply



JWST deep field

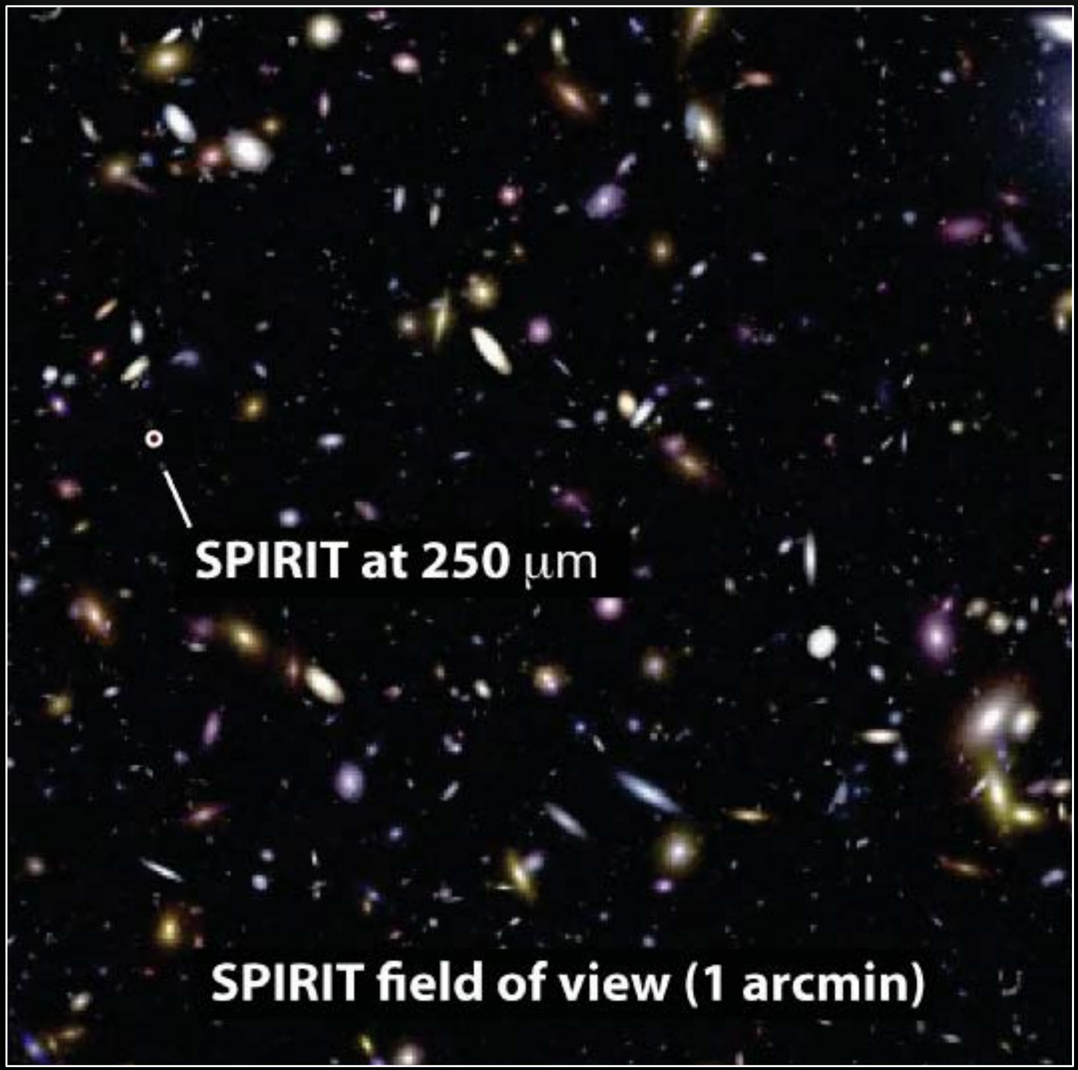
many galaxies per Herschel beam

Probing the universe deeply

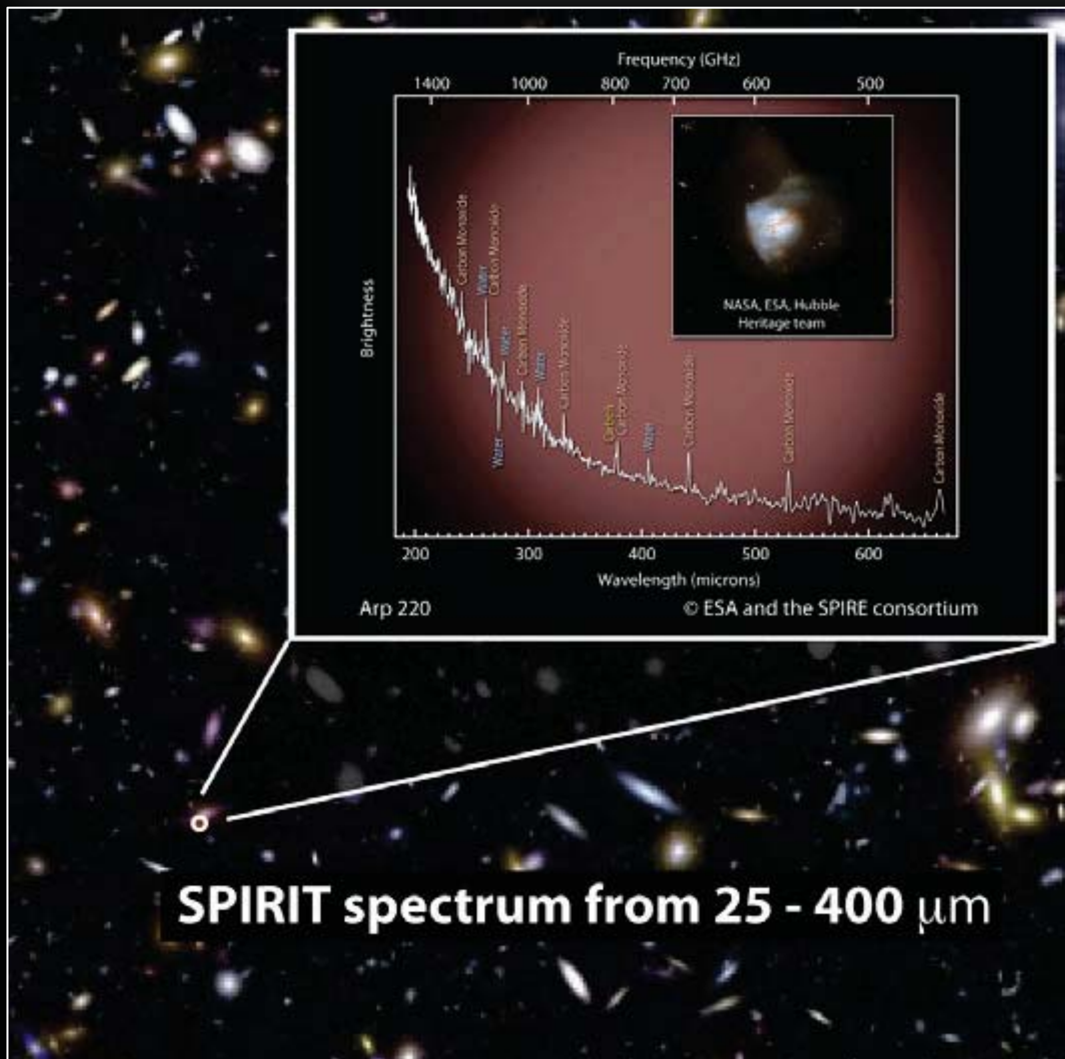


JWST deep field
(1 arcmin cutout)

Probing the universe deeply

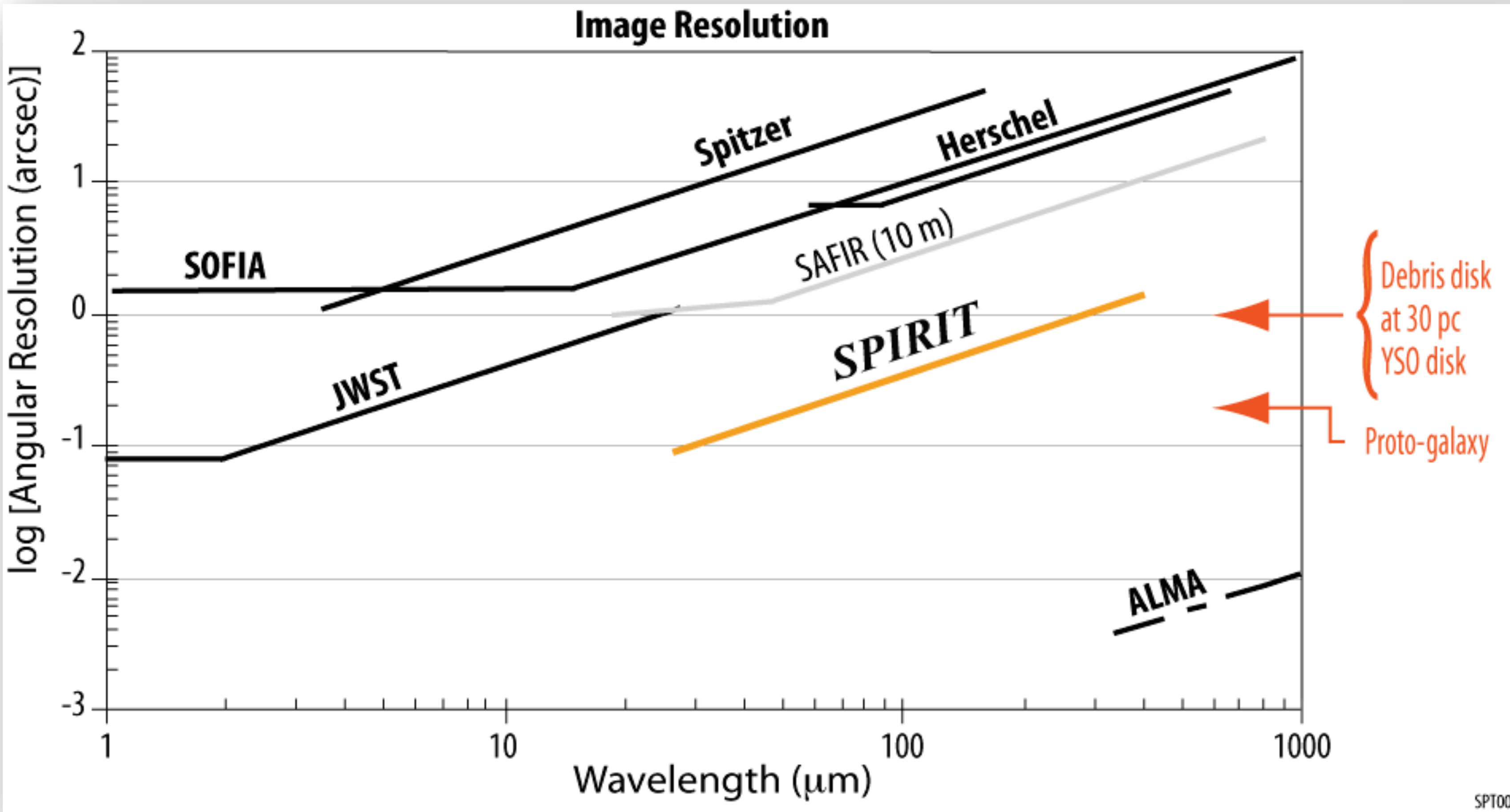


Probing the universe deeply



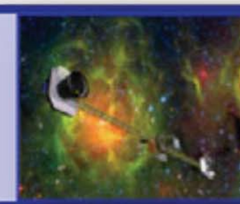
SPIRIT will measure the dominant interstellar gas cooling lines and diagnostic lines in the spectra of individual high-redshift galaxies.

Angular resolution requirement



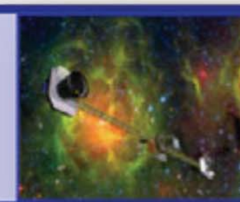
WANTED! Sub-arcsecond angular resolution

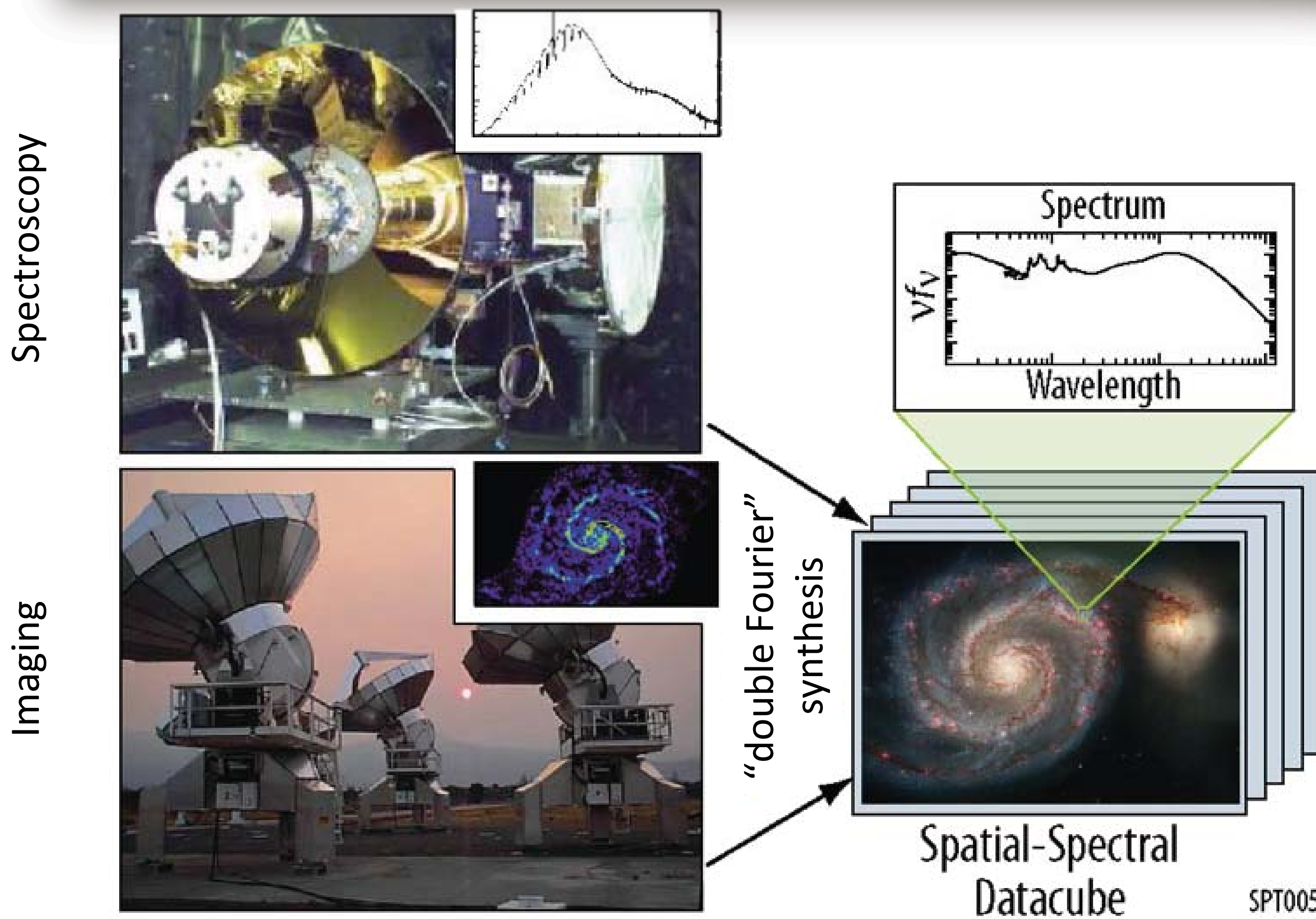
The Challenge



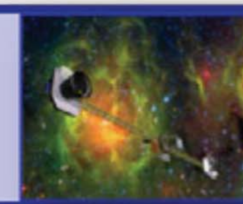
- Diffraction imposes a fundamental limit to image resolution
  - $\theta = 1.2\lambda/D$ at wavelength λ for a telescope of diameter D
- At far-infrared wavelengths, one needs a very large telescope to view the sky with the resolution of JWST (about 1 km to achieve Hubble-class resolution)
- But, there is another way …

The solution: Interferometry



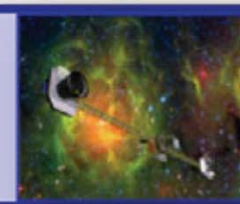


A natural solution …



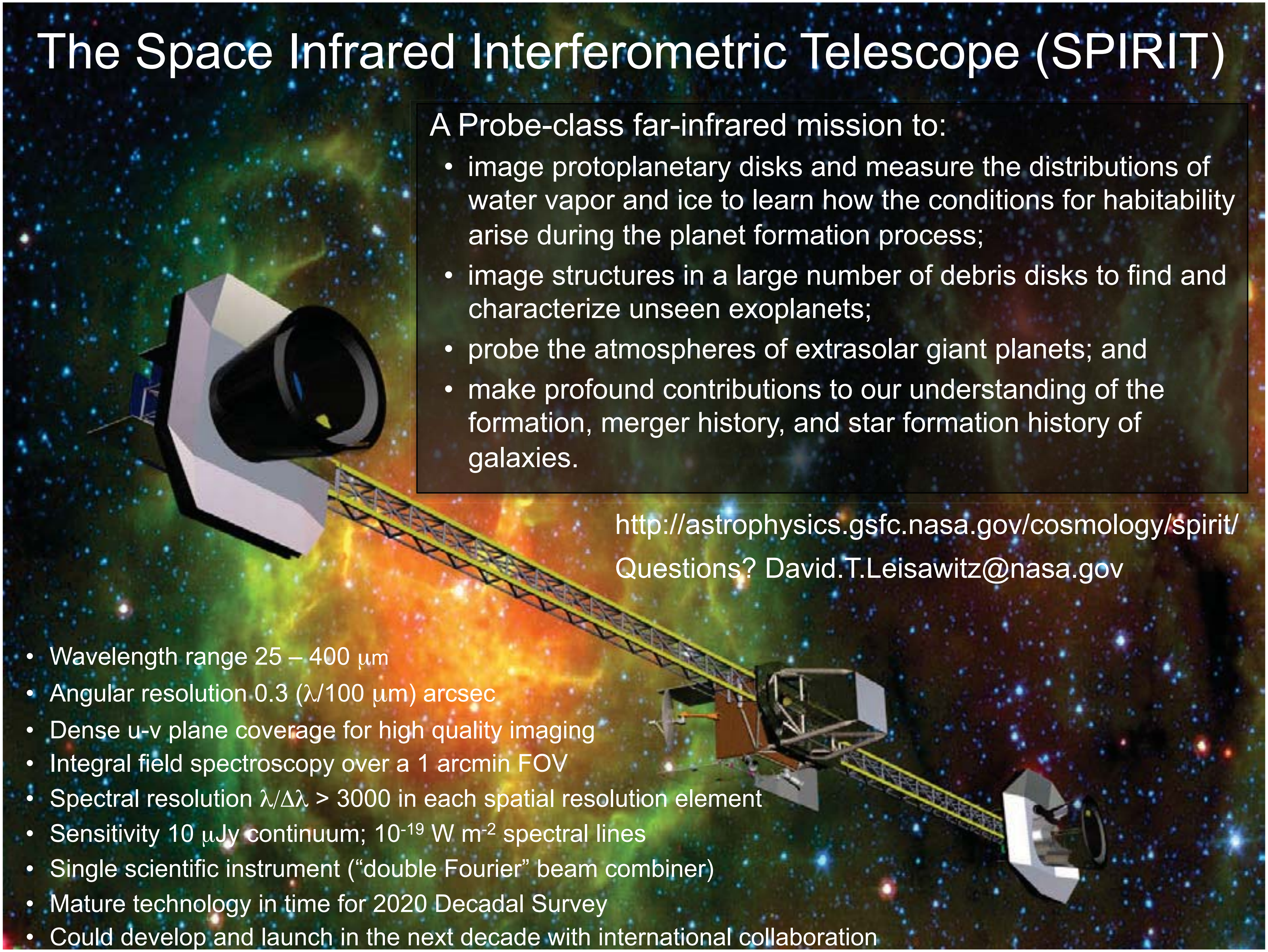
- Interferometry is a natural solution in situations where angular resolution is a much greater driver for telescope size than sensitivity (light collecting area)
- This is overwhelmingly true in the far-infrared
- An interferometer decouples the parameters that affect resolution from those that affect sensitivity, a great advantage!

In summary …



"The human quest to understand our place in the cosmos – How did we get here? – depends on our probing sensitively and in fine detail developing planetary systems and distant galaxies in the far-infrared, and no alternative method is as technically feasible and affordable." – from the Far-IR Community Plan

The Space Infrared Interferometric Telescope (SPIRIT)



A Probe-class far-infrared mission to:

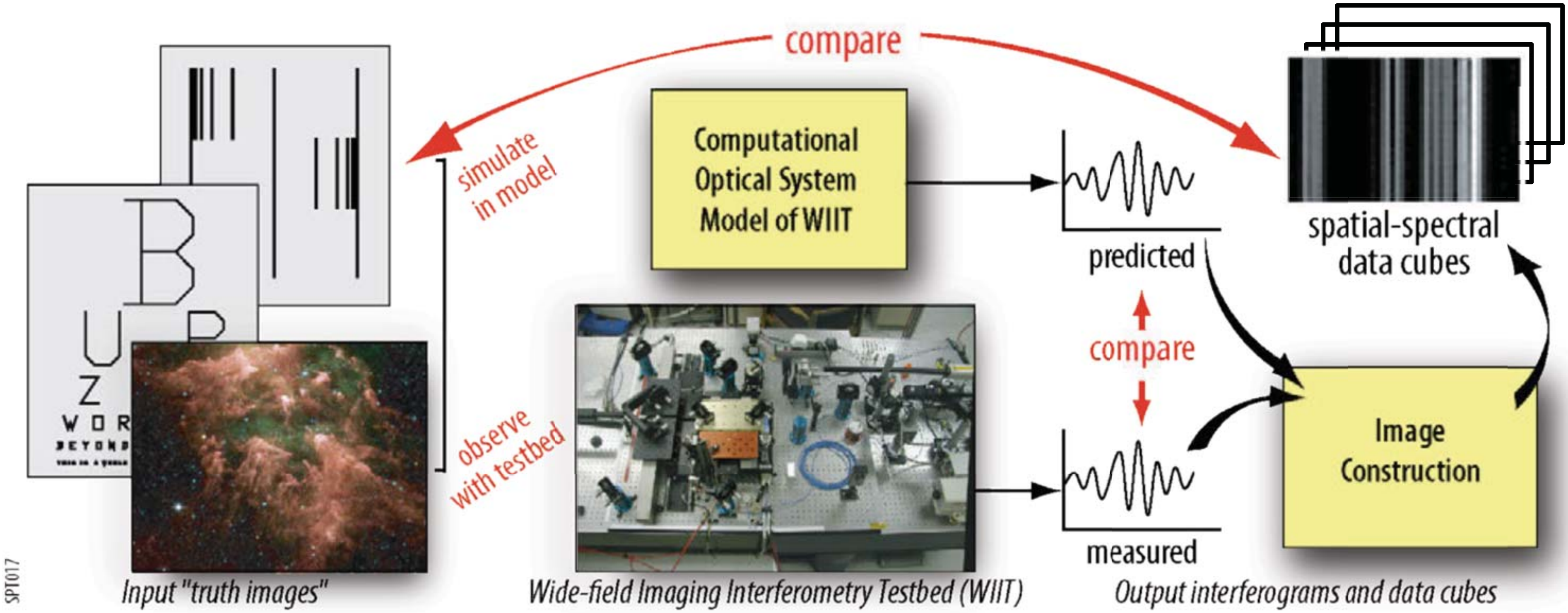
- image protoplanetary disks and measure the distributions of water vapor and ice to learn how the conditions for habitability arise during the planet formation process;
- image structures in a large number of debris disks to find and characterize unseen exoplanets;
- probe the atmospheres of extrasolar giant planets; and
- make profound contributions to our understanding of the formation, merger history, and star formation history of galaxies.

http://astrophysics.gsfc.nasa.gov/cosmology/spirit/

Questions? David.T.Leisawitz@nasa.gov

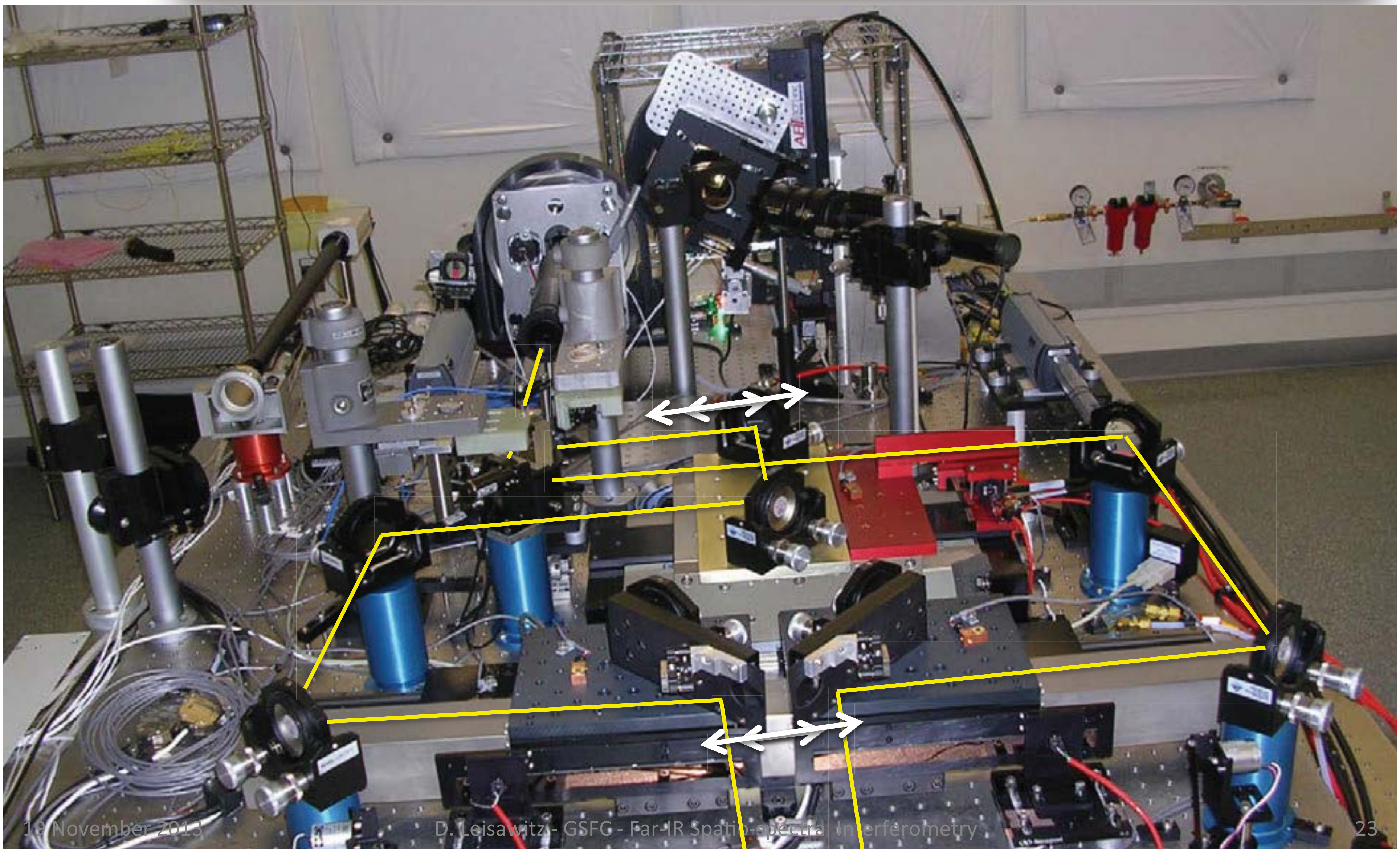
- Wavelength range 25 – 400 μm
- Angular resolution 0.3 (λ/100 μm) arcsec
- Dense u-v plane coverage for high quality imaging
- Integral field spectroscopy over a 1 arcmin FOV
- Spectral resolution $\lambda/\Delta\lambda$ > 3000 in each spatial resolution element
- Sensitivity 10 μJy continuum; 10^{-19} W m^{-2} spectral lines
- Single scientific instrument (“double Fourier” beam combiner)
- Mature technology in time for 2020 Decadal Survey
- Could develop and launch in the next decade with international collaboration

Will it work?

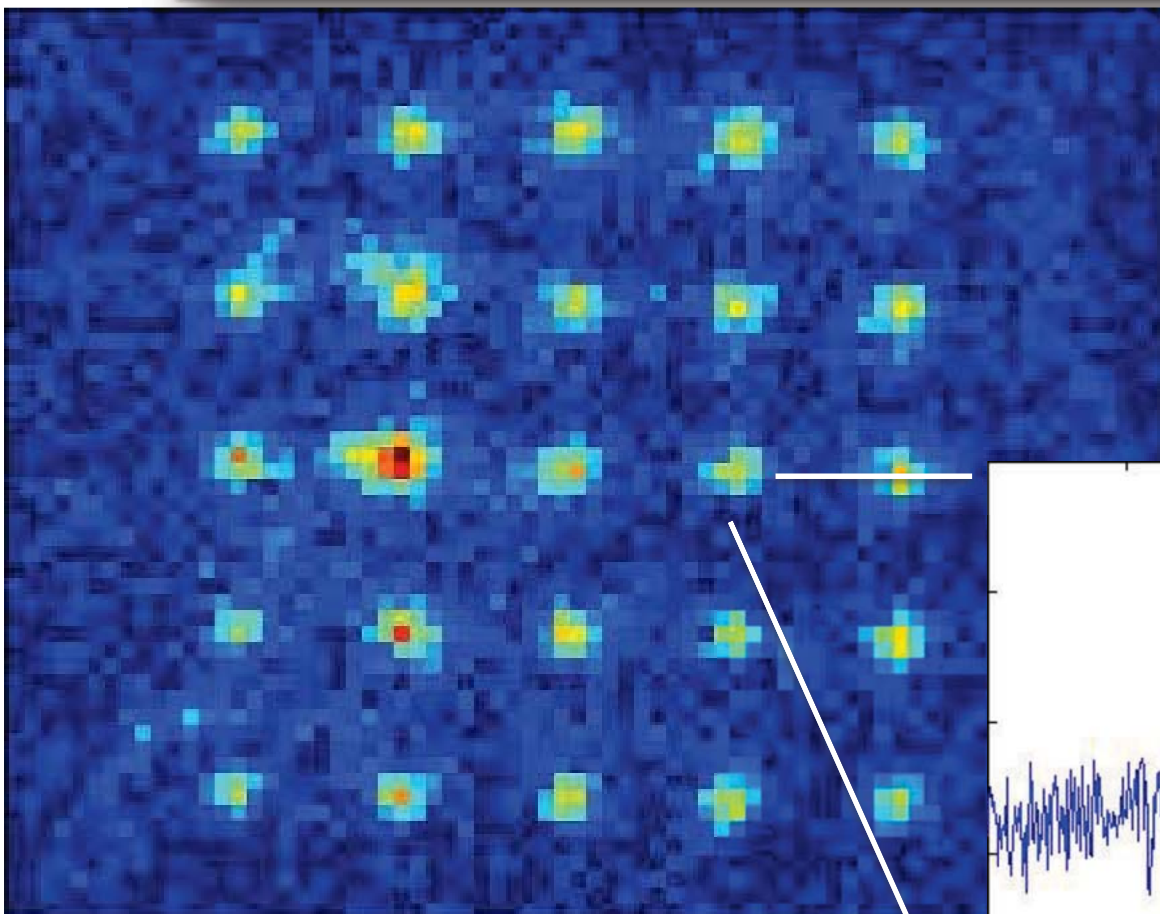


Driving wide-field spatio-spectral interferometry to TRL 6 for far-IR space mission applications. (System model in an operational environment relevant to its intended space flight application.)

Wide-field Imaging Interferometry Testbed

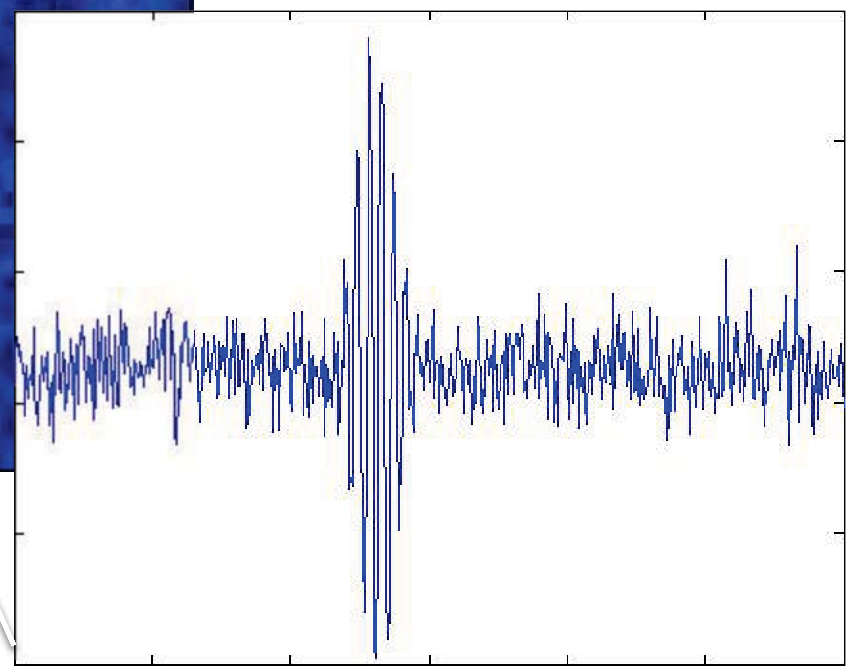


Representative testbed data



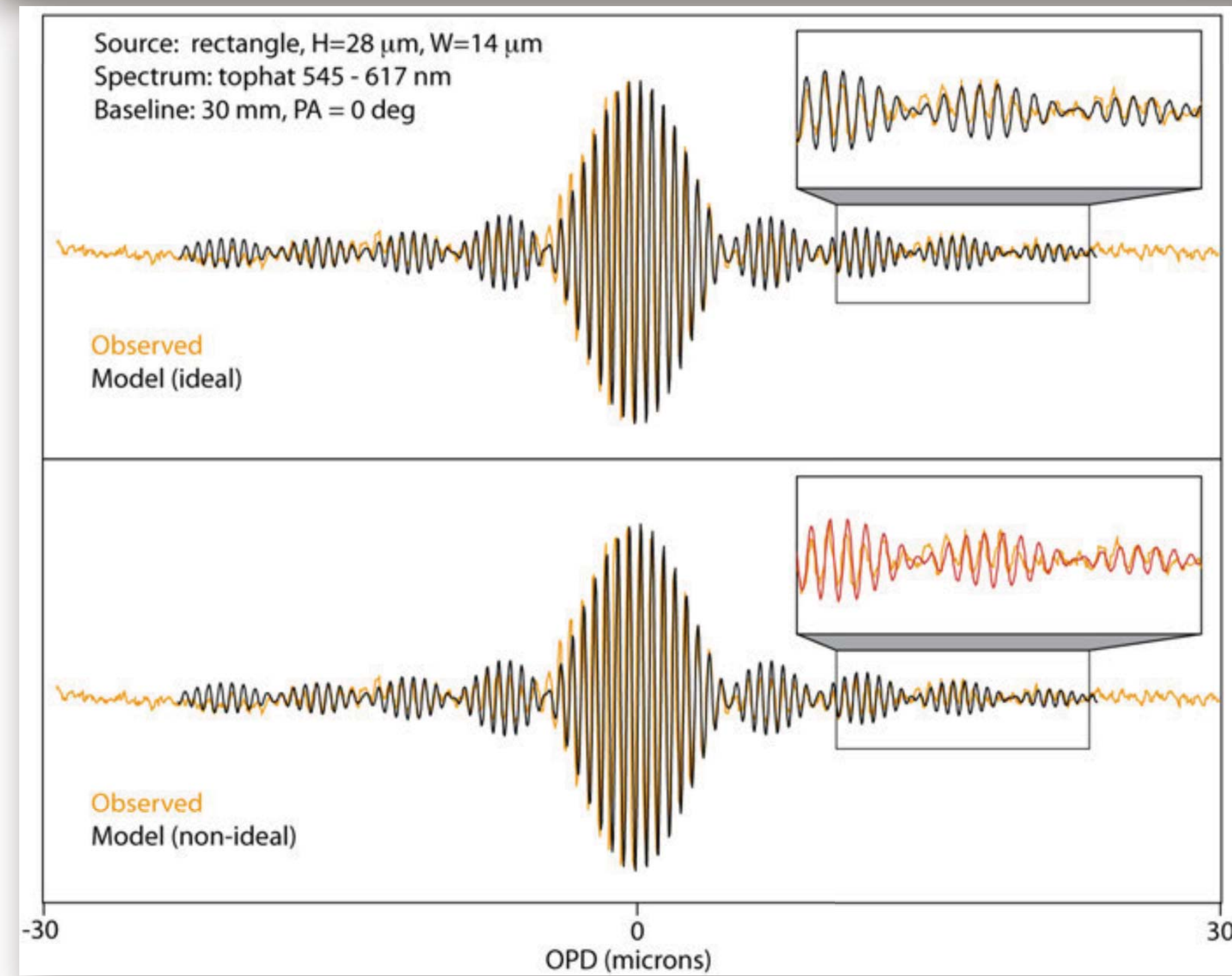
WIIT data from 2012-06-12:

- Baseline: 30 mm
- PA = -90 deg

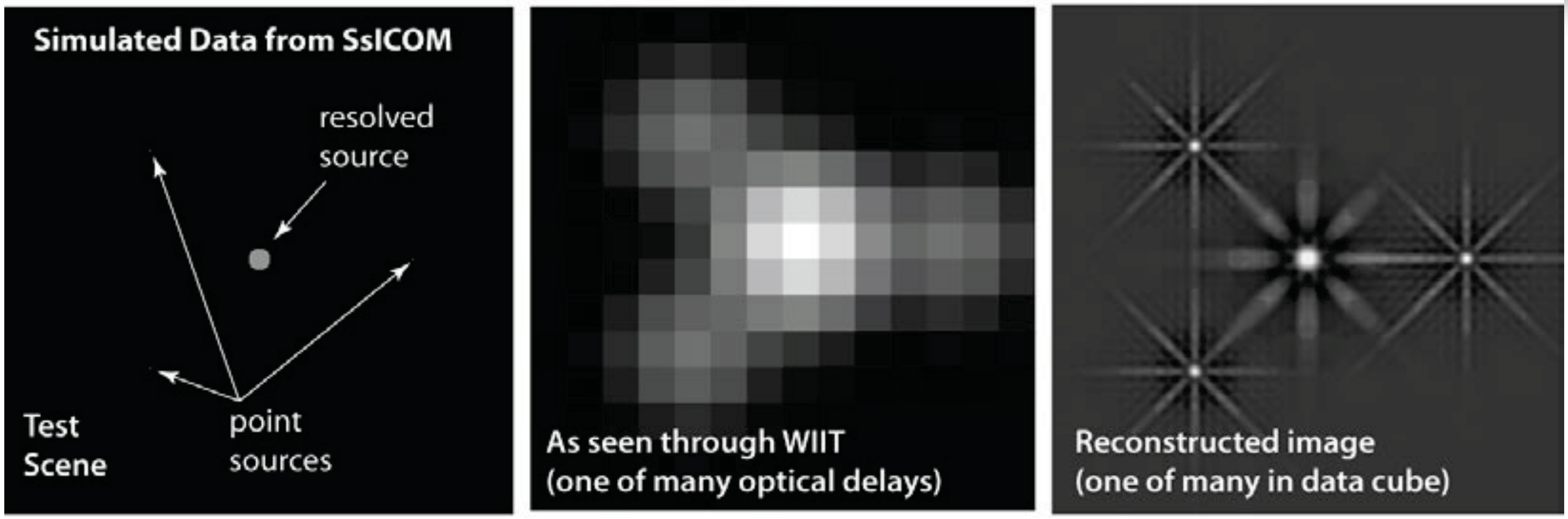


Several hundred baselines like this; dense u-v plane coverage.

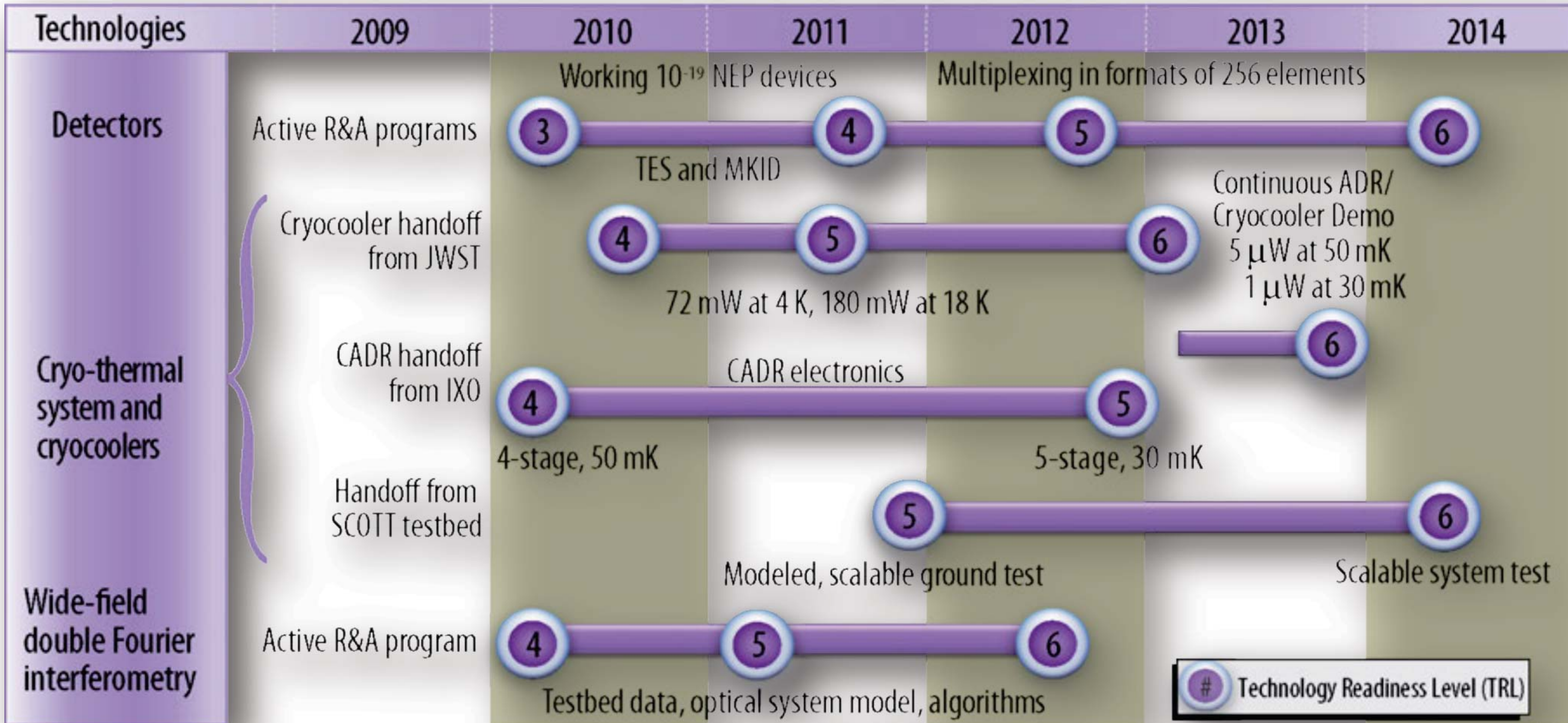
Observed and model interferograms



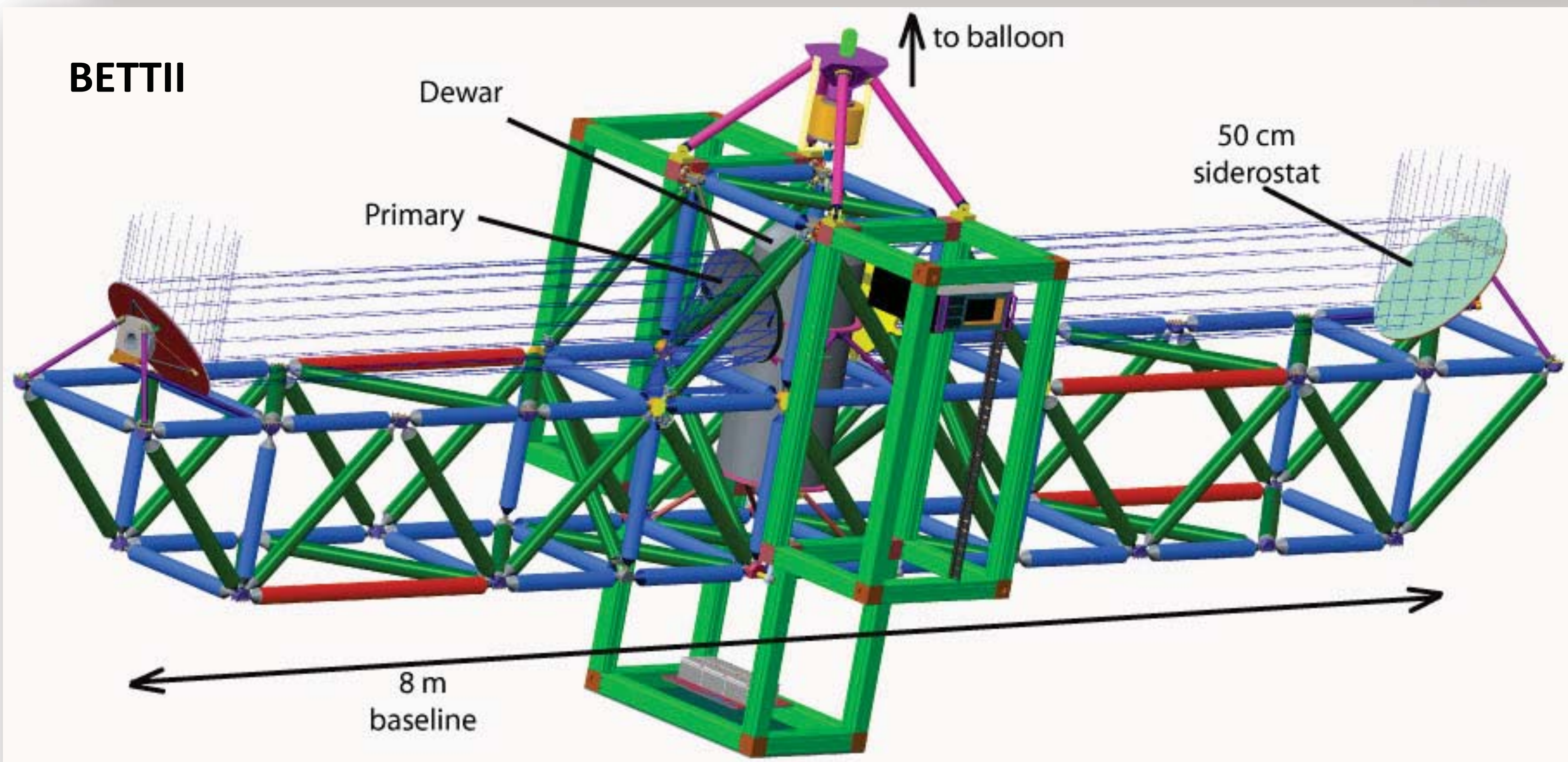
“Double Fourier” synthesis



Technology roadmap

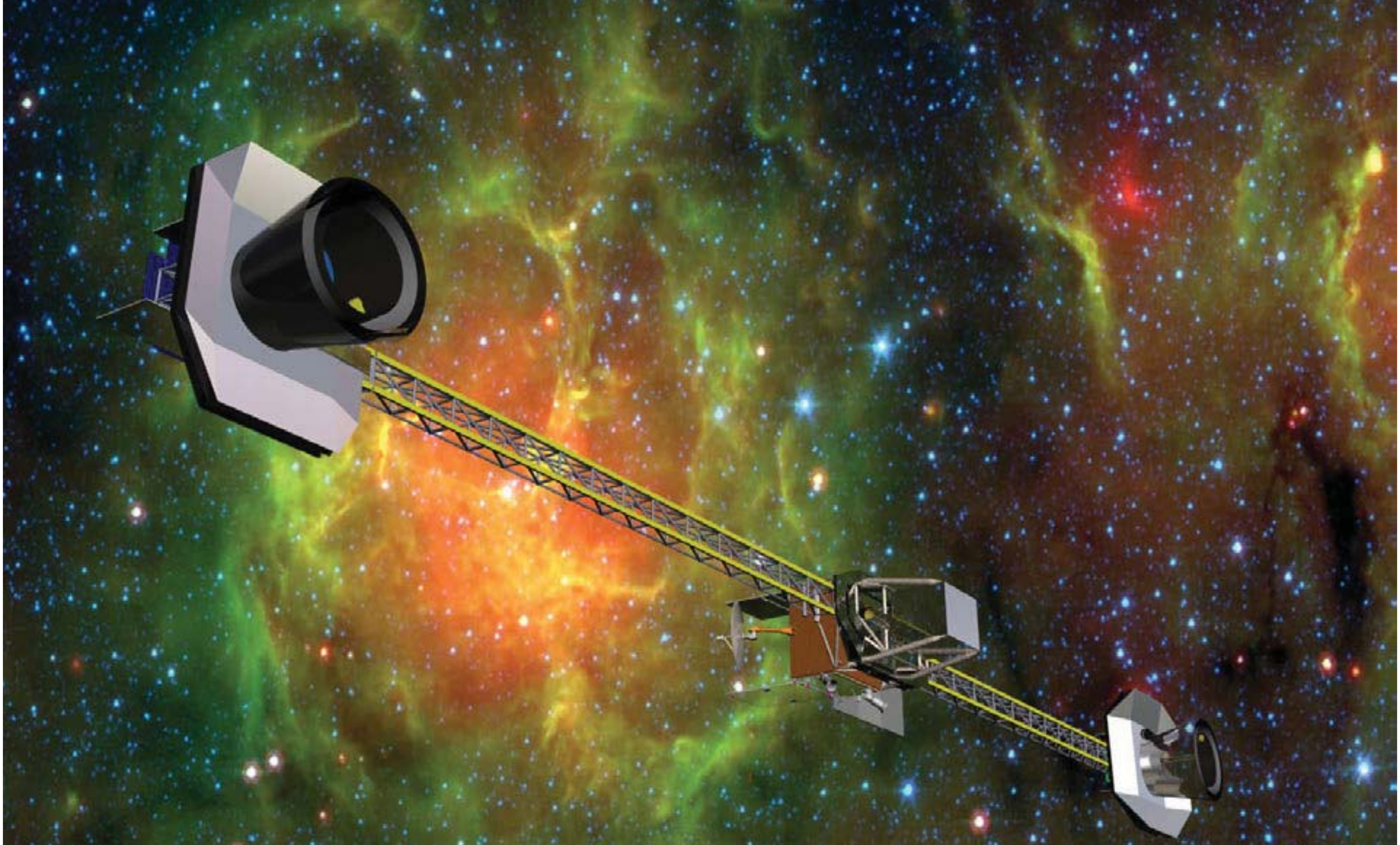


Balloons will come first

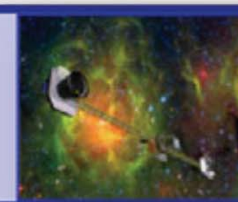


The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII; S. Rinehart, PI) is nearing design completion and will fly in a few years. Japan's Far-IR Interferometric Telescope Experiment (FITE; H. Shibai, PI) is waiting for a maiden flight opportunity.

Maybe next decade, SPIRIT …



Summary



- Important science questions drive the need for high-res imaging and spectroscopy at far-IR wavelengths
  - Formation and habitability of planets
  - Evolution of galaxies over cosmic history
- Interferometry is the natural solution
  - plenty of photons, so we don't need enormous light-collecting area for sensitivity, but
  - we do need much better angular resolution
- We're working in the lab to address practical issues, and the other enabling technologies (detectors, cryocoolers) are being developed in parallel
- Some day, maybe next decade, we'll fly a mission like SPIRIT